First HEP applications of plasma wakefield acceleration

Matthew Wing (UCL) covering
LoI #133 (M. Wing et al., AWAKE++…) and
LoI #170 (S. Gessner et al., Beamdumps…)

- Introduction.
- Search for new phenomena in a beam-dump experiment.
- Deep inelastic scattering experiments.

Introduction

- What can plasma wakefield acceleration deliver for high energy physics ?
- Survey and brainstorm on possible HEP experiments with an electron beam from *O(10 GeV)* up to *TeV* scale.
  - A high energy, high luminosity e^+e^- collider may be the ultimate application, but not the first.
  - Are there experiments with less challenging beam parameters ?
  - The HEP experiment must be achievable with novel plasma wakefield accelerator technology but must have compelling novel particle physics cases.
  - Can learn about acceleration process in less challenging environment (e.g. fixed-target) on way to more challenging applications (collider).
- Laser-driven and beam-driven (electrons or protons) plasma wakefield acceleration should consider what can be achieved.
  - The different types of plasma wakefield acceleration are complementary and one may be more appropriate for a given HEP application.

E.g. a simple roadmap :

Fixed-target → High *E* *ep* collider → High *E*, high lumi e^+e^- collider

Possible “first” HEP experiments/applications

- Use of electron beam for test-beam infrastructure, either / or for detector characterisation and as an accelerator test facility.
- Beam-dump experiments to search for exotics, e.g. dark photons or milliQ.
- Fixed-target experiments using electron beams, e.g. deep inelastic scattering.
- Measure strong-field QED in electron−laser collisions.
- Use as electron injector for EIC.
- High energy electron−proton collider, i.e. a low-luminosity LHeC-type experiment.
- Very high energy electron−proton collider (VHEeP).

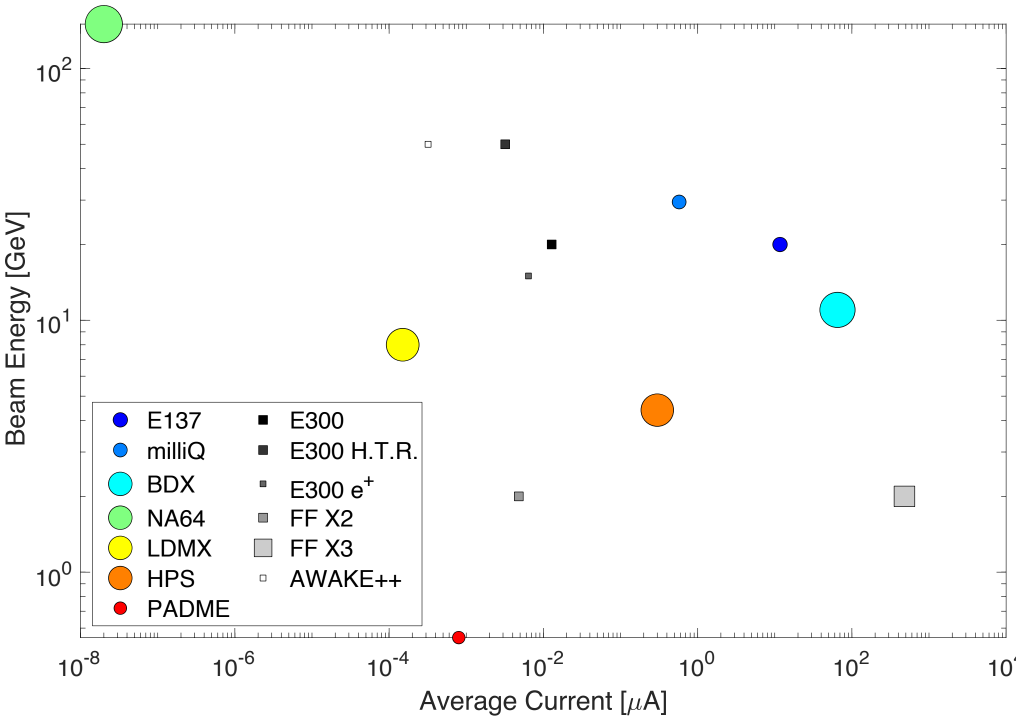
This is not a definitive list and people are invited to think of other possible uses / applications / experiments.

Characteristics for beam-dump experiments

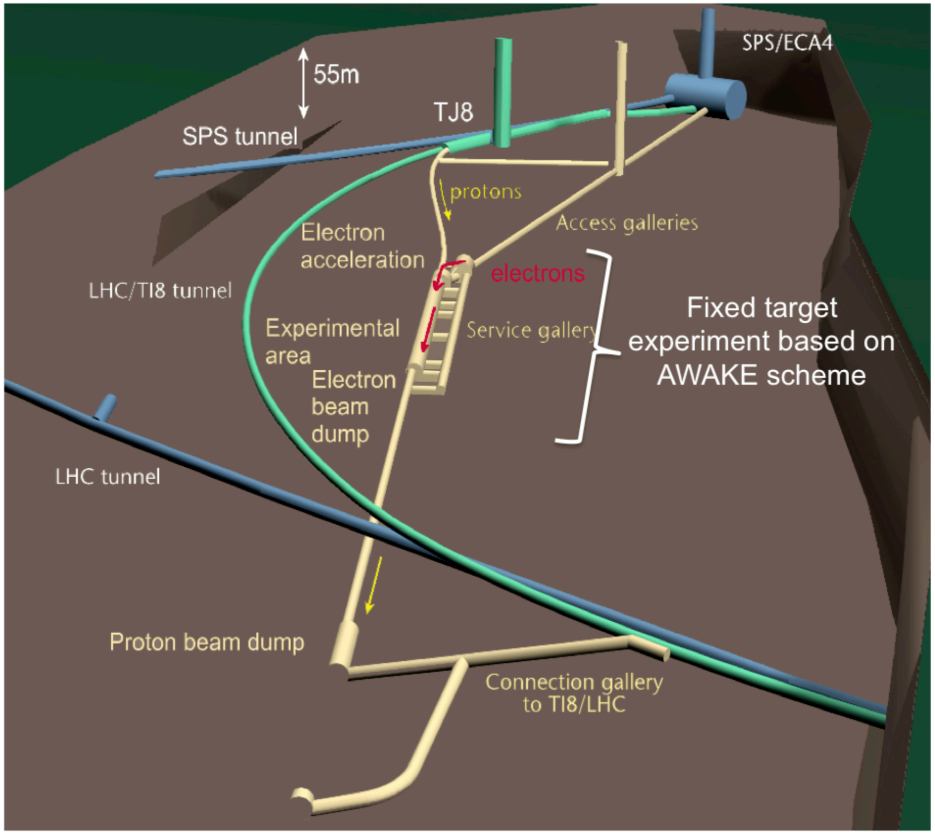
This plot shows past, current, and planned dark sector experiments as coloured circles, and planned PWFA experiments as grey squares.

Plasma accelerators deliver high-charge, short-pulse bunches, which are good for suppressing out-of-time backgrounds in beam-dump experiments.

In order to compete with other proposed beam-dump (thick target) experiments, a plasma-based experiment should deliver high numbers of electrons (or positrons) on target per year or high energy.



AWAKE: electrons in proton-driven plasma wakefield acceleration

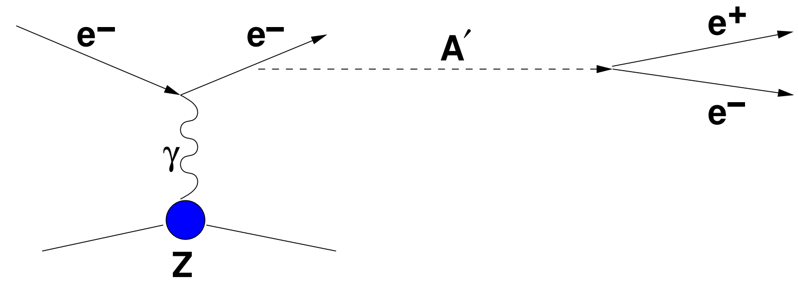


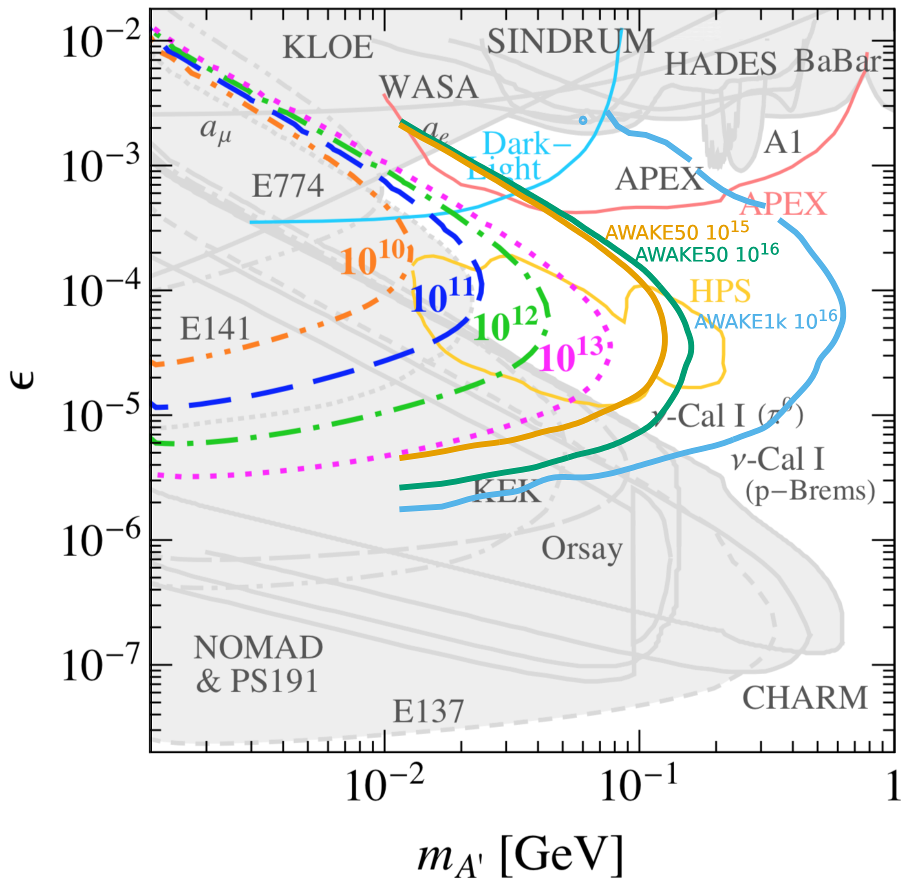
- AWAKE R&D programme based at CERN using *400 GeV* SPS protons
- Facility should have space for fixed-target/beam-dump experiments.
- Aim for *O(50 GeV)* for such facility by end of decade.
- Could also use LHC protons as drivers for *TeV* electrons.
- Limited to where have high energy proton beams, so RHIC/BNL could be used*.

*J. Chappell, A. Caldwell and M. Wing, arXiv:1907.01191

Dark photons search, $A' \rightarrow e^+ e^-$ channel

- Dark sectors with light, weakly-coupling particles are a compelling possibility for new physics.
- Given the paucity of high energy electron beams, a new *50 GeV* facility can make a real impact.
- Based around NA64 experiment but with bunches and more electrons on target.
- Can extend to higher dark photon masses in the region $\varepsilon \sim 10^{-3} - 10^{-5}$.
- Could realise such a beam/experiment within a decade.
- With a *1 TeV* beam, can go to much higher masses:
  - Approaching *1 GeV* for same ε region.
  - Beyond other planned experiments.

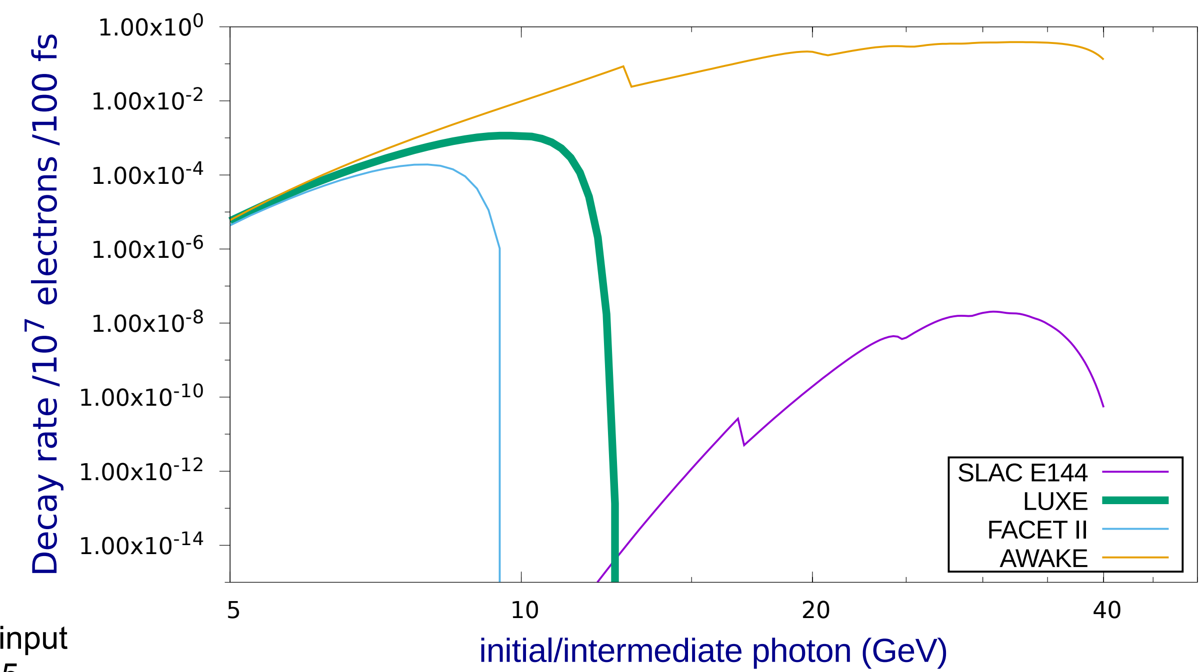




A. Caldwell et al., arXiv:1812.11164, EPPSU input
M. Wing, Phil. Trans. R. Soc. A 377: 20180185.

Strong-field QED

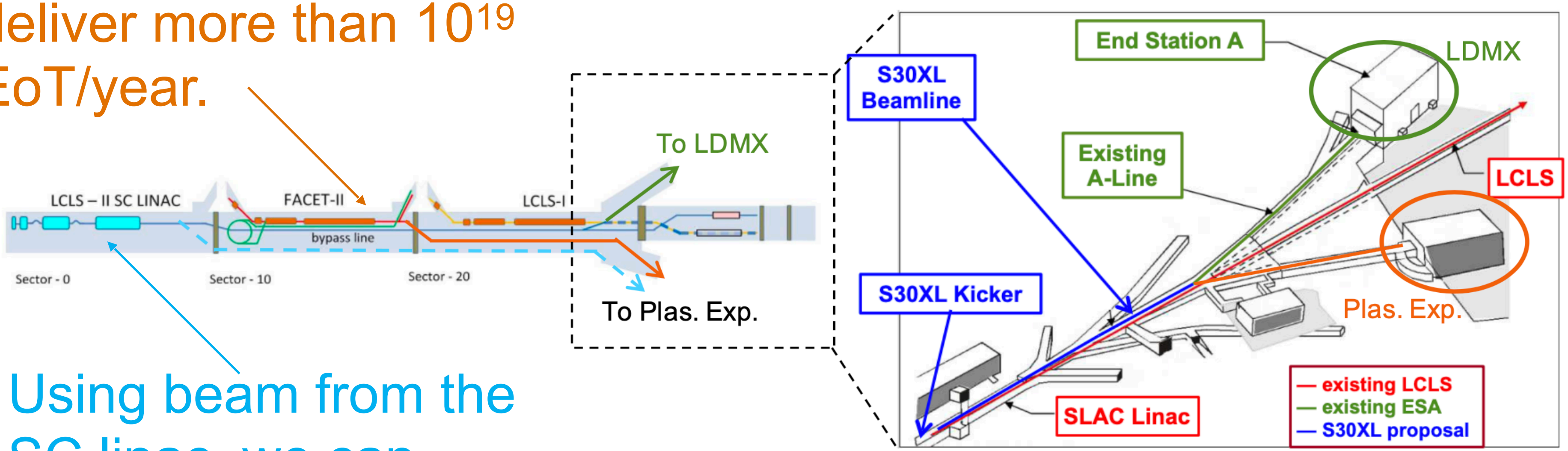
- The same *O(50 GeV)* beam could be brought into collision with a high-power laser.
- Study strong-field QED at values related to the Schwinger critical field.
- Follows on from pioneering E144 experiment at SLAC.
- High energy electron beam can be used for measurements of strong-field QED:
  - See efforts at EuXFEL and FACET-II, etc. and earlier session.
  - Higher energy leads to gains.



A. Caldwell et al., arXiv:1812.11164, EPPSU input
M. Wing, Phil. Trans. R. Soc. A 377: 20180185.

Concept @ SLAC

Using beam from the NC linac, we can deliver more than 10^{19} EoT/year.



Using beam from the SC linac, we can deliver more than 10^{21} EoT/year.

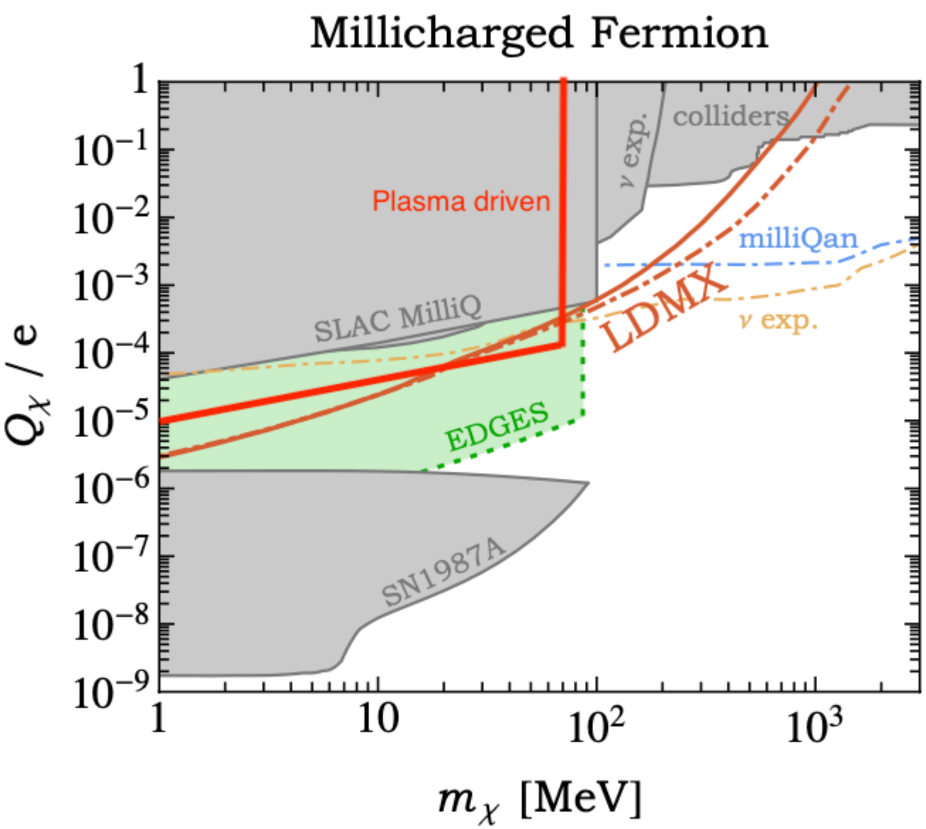
Accelerator	Linac Energy	After Plasma	Bunch Charge	Rate	Current	EOT/year
NC to ESB	10 GeV	20-50 GeV	$0.2\text{-}2.0\times10^{10}$	120 Hz	19-190 nA	$0.4\text{-}4\times10^{19}$
SC to ESB	8 GeV	16-40 GeV	$0.3\text{-}3.0\times10^{9}$	1-62.5 kHz	0.5-30 μA	$0.1\text{-}6.0\times10^{21}$

Example Search: Millicharged Particles

As an example, we examine the exclusion curve from the SLAC MilliQ experiment and assume:

- 10x increase in EoT over milliQ
- 10x increase in detector sensitivity
- Beam energy scaled down to *20 GeV* from *30 GeV* for the 1998 experiment.

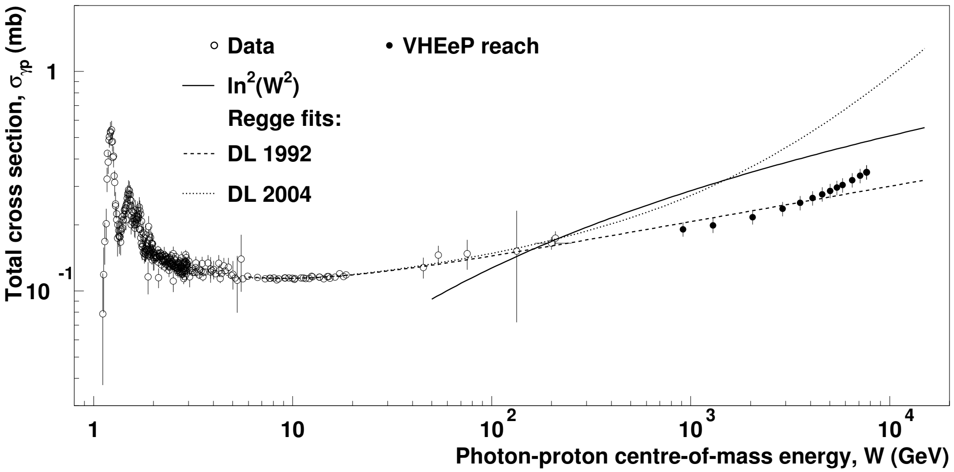
Achieving 10x increase in EoT requires 2 years of operation with NCRF linac at SLAC or a few weeks of operation with the new SCRF LCLS-II linac.



Deep inelastic scattering

- *50 GeV* electrons on fixed-target give $\sqrt{s}$ ~ *10 GeV*; interesting ?
- *TeV* electrons on a fixed-target give $\sqrt{s}$ ~ *50 GeV*, similar to EIC energies.
- *50 GeV* electrons colliding with LHC protons gives $\sqrt{s}$ ~ *1 TeV*, i.e. LHeC energies.

- Use LHC as driver for $E_e = 3$ *TeV* and $\sqrt{s}$ **= 9.2 *TeV***, but with modest luminosities, $O(10^{28}-10^{29}\ cm^{-2}\ s^{-1})$: VHEeP.
- Completely new regime, well beyond other *ep* colliders; exciting physics potential.
- Revolutionise QCD; new theories; links to gravity, cosmic rays, etc..



- *ep* experiments, fixed-target or colliding beams, do not require electron beam parameters as challenging as e.g. ILC.
- *ep* experiments do not necessarily need positrons, although they do provide extra physics.

Discussion

- Plasma wakefield acceleration has near-term applications in HEP on the timescale of a decade.
- Beam-dump experiments are compelling applications:
  - Less challenging beam parameters for PWA to achieve.
  - Searches for new physics possible with expected PWA beams.
  - Input from HEP, detectors, theory, etc., would be welcome.
  - Ideas at AWAKE and SLAC already show potential.
  - Other PWA projects/facilities should also consider whether they can generate appropriate beams.
  - More thorough survey of beam-dump experiments with PWA beams would be good to consider all possibilities.

Discussion

- What other near-term possibilities are there for PWA ?
- Electron−proton collider could be an application.
  - At AWAKE++, we considered LHeC-type machine:
    - Electrons of energy *50 GeV* should be doable.
    - Small amount of civil construction.
    - Modest luminosity limited by proton driver from SPS.
    - But may be a cost-effective option.
  - What about other PWA techniques ?
    - Could e.g. laser wakefield acceleration generate 10s of GeV beams with suitable repetition rate and minimal civil construction on timescale of end of planned LHC running ?
  - An LHeC-like experiment would be an excellent application for PWA and should be considered more seriously.
- We should think beyond ultimate applications for PWA and think what can be done in the near-term.